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(54) Optical disc substrate

(57) An optical disc substrate (1) with deep grooves (3) having a depth of $\lambda/4n$ to $\lambda/2n$, where λ is the wavelength of a laser beam of an optical pickup and n is the refractive index of a substrate. The optical disc substrate includes: a plurality of deep grooves (3) having a predetermined depth, individual deep grooves having sidewalls slanted at an angle of θ; and a plurality of lands (5) having the same level as the surface of the substrate, wherein a depth D of a groove for minimum crosstalk is determined by the following mathematical relation

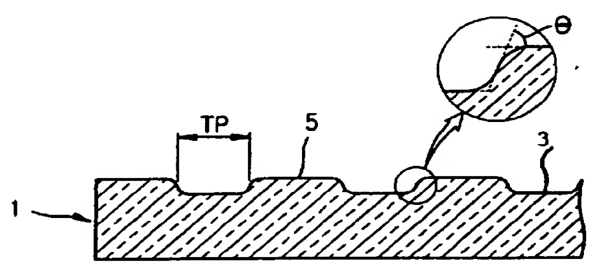
$$D = 0.4022-0.4574x\ A+0.6458x\ A^2$$

Where D = *physical groove depth* $x\frac{n}{\lambda}$

$$A=\frac{NA \cdot TP}{\lambda}x\frac{1}{\sin^2\theta},$$

TR indicates the track pitch of a disc substrate,
NA indicates the numerical aperture of an objective lens of an optical pickup,
θ is the slant angle of grooves between lateral extension of lands or grooves and extension of groove sidewalls,
λ is the wavelength of a laser beam of the optical pickup; and
n is the refractive index of the substrate.

FIG.1



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Description

[0001] The present invention relates to a substrate of an optical disc with lands and grooves, and more particularly, to an optical disc substrate with deep grooves having a depth of $\lambda/4n$ to $\lambda/2n$, where λ is the wavelength of a laser beam emitted from an optical pickup and n is the refractive index of a substrate.

[0002] Optical discs are information recording media adopted by a disc player, which writes and/or reads information in a non-contact manner. The need for a high recording density at a limited data recording portion has suggested an optical disc substrate which allows data writing on both its grooves and lands.

[0003] Figure 1 is a schematic view of an existing optical disc substrate adopting a land-and-groove recording method. As shown in Figure 1, an optical disc substrate 1 is comprised of a plurality of tracks spirally formed from the center to the periphery of an optical disc, alternately forming a plurality of grooves 3 having a predetermined depth and a plurality of lands 5 having the same level as the surface of the optical disc substrate.

[0004] In particular, the format book for a 2.6-gigabyte DVD-RAM suggests a ratio of the land width and the groove width be approximately 50 : 50. A land-and-groove recording method applied to such an optical disc having the above configuration is advantageous in that a difference in height between lands and grooves reduces crosstalk, which is noise generated from adjacent tracks, and writing on both lands and grooves increases the recording density. Another advantage of the land-and-groove recording method is a larger amplitude of a push-pull signal compared to a recording method which allows writing on either lands or grooves. This larger amplitude of the push-pull signal is because an optical track pitch which causes the push-pull signal is half the size of a data track pitch.

[0005] For a high recording density in optical discs having the above configuration, the track pitch (TP) must be reduced. In this case, the size of a write beam spot must be reduced to keep the same writing and reading characteristics. However, as the recording capability of optical DVDs increases, a relative track pitch with respect to the write beam spot size decreases, which is shown in Table 1, causing "cross erase" which refers to erasure of signals on adjacent tracks, and thus limiting the increase in recording density.

Table 1

Items	Type of Recording Media			
	2.6GB DVD-RAM	4.7GB DVD-RAM	15GB HD-DVD	18GB HD-DVD
Wavelength of laser beam (nm)	650	650	400	400
Numerical aperture (NA)	0.6	0.6	0.6	0.65
Track pitch (μm)	0.74	0.615	0.34	0.30
Ratio of track pitch to beam spot size	0.68	0.57	0.51	0.49

[0006] The cause of cross erase can be summarized into two factors. One is thermal absorption of write beam by adjacent tracks, and the other is thermal transfer to adjacent tracks during writing. The thermal transfer between recording layers in an optical disc, which causes a temperature increase in the optical disc, can be avoided by spacing adjacent tracks further apart.

[0007] In this way, an optical disc with deep grooves has been proposed. In a case such as an optical disc, the groove depth is larger than the groove depth **Gd**, $\lambda/6n$, where λ is the wavelength of a laser beam of an optical pickup and n is the refractive index of an optical disc substrate, of a general optical disc, which elongates the thermal conductive distance and in turn suppresses occurrence of both cross erase and crosstalk. However, the problem with deep-groove optical discs is the phase reversion of a tracking error signal, so called "push-pull signal" at a depth below than a predetermined depth.

[0008] Figure 2 shows the push-pull ratio (PPR), divided push-pull ratio (DPP) and on-track ratio (OTR) for a 4.7-gigabyte DVD-RAM with respect to the depth of grooves.

[0009] Phase reversal of the push-pull signal means that the deep grooves are tracked according to the tracking conditions for lands of a general optical disc as shown in Figure 1. Since the tracking conditions for lands and grooves cannot be the same, the DVD-RAM format described with reference to Figure 1 delimits the depth of grooves to be less than or equal to $\lambda/4n$, where λ is the wavelength of a laser beam for optical pickup and n is the refractive index of an optical disk substrate, which permits the same phase of push-pull signals for lands and grooves.

[0010] The crosstalk signal and push-pull signal are influenced by a slant angle θ of grooves. As shown in Figure 1, the slant angle θ of grooves refers to the angle between lateral extension of lands or grooves and extension of groove sidewalls.

[0011] Figure 3 illustrates the crosstalk and the push-pull signal for an optical pickup adopting an objective lens having a numerical aperture (NA) of 0.6 with respect to the groove depth when the slant angle θ of grooves is 60° and 80°. In FIGURE 3, *A* and *B* indicate the crosstalk signals at the slant angle θ of groove of 60° and 80°, respectively. *C* and *D* indicate the push-pull signals at the slant angle θ of grooves of 60° and 80°, respectively.

[0012] For the result of Figure 3, the groove depth has been normalized based on the wavelength (λ) of the incident laser beam and the refractive index (*n*) of the disc substrate. In Figure 3, the horizontal dashed line at the push-pull signal of 0 indicates an optical groove depth of $\lambda/4n$. Thus, it can be concluded that the optical groove depth for a predetermined wavelength of a laser beam varies depending on the slant angle θ of grooves even at the same physical groove depth. Also, as previously mentioned, the phase of the push-pull signal reverses around the optical groove depth of $\lambda/4n$. Also, the push-pull signal of deep grooves varies depending on the slant angle θ of grooves.

[0013] Figure 3 shows that when the physical depth of grooves is small, the effect of the slant angle θ of grooves on variation of push-pull signal and crosstalk signal is negligible, compared to that of the groove depth. However, as the physical depth of grooves increases, variations of the push-pull signal and crosstalk signal with respect to the slant angle θ of grooves, i.e., at 60° and 80°, increase.

[0014] It is an aim of the present invention to provide an optical disc substrate with deep grooves having a depth of $\lambda/4n$ or more, where λ is the wavelength of a laser beam from an optical pickup and *n* is the refractive index of a substrate, which results in improved crosstalk and cross erase characteristics.

[0015] The present invention provides an optical disc substrate for land-and-groove recording, comprising: a plurality of deep grooves having a predetermined depth, individual deep grooves having sidewalls slanted at an angle of θ; and a plurality of lands having the same level as the surface of the substrate, wherein a depth D of a groove for minimum crosstalk is determined by the following mathematical relation [1]

$$D = 0.4022 - 0.4574 \times A + 0.6458 \times A^2 \qquad [1]$$

[0016] Where $D = \text{physical groove depth} \times \frac{n}{\lambda}$

$$A = \frac{NA \cdot TP}{\lambda} x \frac{1}{\sin^2\theta}$$

TR indicates the track pitch of a disc substrate,

NA indicates the numerical aperture of an objective lens of an optical pickup,

θ is the slant angle of grooves between lateral extension of lands or grooves and extension of groove sidewalls,

λ is the wavelength of a laser beam of the optical pickup; and

n is the refractive index of the substrate.

[0017] Preferably, an effective groove depth D_{eff} is determined by the following mathematical relation [2]

$$D_{eff} = D \pm 0.844 \cdot NA \qquad [2]$$

[0018] Preferably, the track pitch *TR* and slant angle θ of grooves satisfies the following relations [3] and [4]

$$\tan\theta \geq \frac{D}{TP - W_m} \qquad [3]$$

where W_m is the width of a minimum record mark, and

$$\sin^2\theta \geq 1.25 x \frac{NA \cdot TP}{\lambda} \qquad [4].$$

[0019] For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings in which:

Figure 1 is a sectional view of a conventional optical disc substrate employing a land-groove recording method;

Figure 2 illustrates the push-pull ratio (PPR), the divided push-pull ratio (DPP), the on-track ratio (OTR) for a 4.7 gigabytes DVD-RAM with respect to the depth of grooves;

Figure 3 illustrates the crosstalk signal and push-pull signal for an optical pickup adopting an objective lens having a numerical aperture (NA) of 0.6 with respect to the depth of grooves when the slant angle θ of grooves is 60° and 80°;

Figure 4 illustrates the crosstalk signal with respect to the depth of grooves when a track pitch varies at 0.26, 0.30, 0.34 and 0.40μm and the slant angle of grooves at 60° and 80°;

Figure 5 illustrates the crosstalk signal with respect to the depth of grooves when the numerical aperture of an objective lens varies at 0.60, 0.63, 0.65 and 0.67;

Figure 6 shows waveforms illustrating jitter characteristics of a substrate with shallow grooves, measured by oscilloscopy; and

Figure 7 shows waveforms illustrating jitter characteristics of a substrate with deep grooves according to the present invention, measured by oscilloscopy.

[0020] Similar to the conventional optical disc described with reference to Figure 1, a substrate according to the present invention includes a plurality of deep grooves having a predetermined depth and a plurality of lands having the same level as the surface of the substrate. The grooves have sidewalls slanted at an angle of θ.

[0021] The present invention relates to delimiting the depth and slant angle θ of deep grooves of a substrate using mathematical relations based on the result of experiments, and improving crosstalk, cross erase and tracking characteristics in a deep groove configuration with a depth greater than and equal to $\lambda/4n$, where λ is the wavelength of a laser beam of an optical pickup and n is the refractive index of a substrate.

[0022] Results of experiments are shown in Figures 4 and 5. Figure 4 illustrates the crosstalk signal with respect to the depth of grooves when a track pitch varies at 0.26, 0.30, 0.34 and 0.40μm and the slant angle of grooves at 60° and 80°. For this observation, a laser beam having a wavelength of 410 nm was irradiated onto a disc and the numerical aperture (NA) of an objective lens used was 0.65.

[0023] Figure 5 illustrates the crosstalk signal with respect to the depth of grooves when the numerical aperture of an objective lens varies at 0.60, 0.63, 0.65 and 0.67. In this observation, the wavelength of a laser beam irradiated was 410 nm, the track pitch (TP) of a disc was 0.34μm, and the slant angle θ of grooves was 70°.

[0024] As shown in Figures 4 and 5, the depth and slant angle of grooves, the track pitch and the NA influence on occurrence of crosstalk from adjacent tracks. The effect of these factors on the crosstalk will be qualitatively summarized as below. First, as for the depth of grooves, the most effective factor on crosstalk, a crosstalk offset point exists in respective relatively shallow and deep groove ranges, as shown in Figure 4. A smaller track pitch and a larger slant angle of grooves shift a minimum crosstalk point in grooves upward near the surface of substrate. Meanwhile, a higher NA tends to shift the minimum crosstalk point down and requires deeper grooves for minium crosstalk. Also, a groove depth margin for minimal crosstalk is wider at a higher NA, compared to at a smaller NA.

[0025] The above-mentioned qualitative relation of the groove depth, the track pitch, the slant angle of grooves and the NA with respect to crosstalk, in particularly, for minimum crosstalk, can be expressed as the following mathematical relation [1]. For the mathematical relation [1], the NA was varied from 0.6 to 0.67, the track pitch was varied from 0.26 to 0.40 μm, and the slant angle of grooves was varied from 50 to 88° to decide the minimum crosstalk depth in deep grooves.

$$D = 0.4022-0.4574x\ A+0.6458x\ A^2 \qquad [1]$$

[0026] Where $D = physical\ groove\ depth\ x\frac{n}{\lambda}$

$$A=\frac{NA \cdot TP}{\lambda}x\frac{1}{\sin^2\theta},$$

[0027] θ is the slant angle of grooves between lateral extension of lands or grooves and extension of groove sidewalls.

[0028] Since the above mathematical relation is not practically applicable to the entire groove depth range, it is desirable to define an effective groove depth D_{eff} at which at least phase reversal of push-pull signal does not occur, based on the groove depth D which satisfies the mathematical relation [1]. In particular, the minimum difference between the groove depth at which the push-pull signal has zero value and the minimum crosstalk depth is approximately 15 nm, approximately 0.0844 in normalized units, and thus a groove depth region within $\pm$ 0.0844 $\cdot$ NA from the minimum crosstalk depth can be set as a crosstalk offset region in deep grooves. The effective groove depth D_{eff} can be expressed by the following mathematical relation [2].

$$D_{eff} = D \pm 0.844 \cdot NA \qquad [2]$$

[0029] The ranges of track pitch and slant angle of grooves are determined as follows. First of all, the lower limit of track pitch in a substrate according to the present invention must be equal to the width of a recording portion of lands or grooves, which is greater than or equal to the width of a record mark. The upper limit of track pitch varies depending on the slant angle θ of grooves. From this point of view, the track pitch with respect to the width of a minimum record mark, and the angle of grooves must satisfy the following relation [3]

$$\tan\theta \geq \frac{D}{TP - W_m} \qquad [3]$$

where W_m is the width of the minimum record mark.

[0030] Another consideration for such a deep groove configuration according to the present invention is the crosstalk minimum depth. The crosstalk minimum depth is also influenced by the track pitch and the slant angle of grooves. However, if the crosstalk minimum depth is greater than a predetermined depth in grooves, the push-pull signals become too small to enable tracking. For example, if the groove depth is greater than or equal to 135 nm, the push-pull signal drops to 0.2 or less, which causes tracking failure. For this case the crosstalk minimum depth is determined to be 120 nm taking into account the marginal values determined by the relation [2]. Thus, it is preferable that the track pitch and the slant angle of grooves satisfy the following relation [4]

$$\sin^2\theta \geq 1.25 x \frac{NA \cdot TP}{\lambda} \qquad [4]$$

[0031] Preferably, the slant angle of grooves and the track pitch are determined within the range satisfying the conditions of both of the relations [3] and [4].

[0032] In addition, the upper limit of slant angle of grooves cannot be greater than or equal to 90°. The upper limit of the track pitch is determined according to the conditions of optical recording systems, for example, recording capability and coding conditions, which is expressed by the following relation [5]

$$\textit{upper limit off track pitch} = \frac{\textit{area of recordable region on optical disc}}{\textit{minimum length of bytes x amount of requred data}} \qquad [5]$$

where *area of recordable region on optical disc* is $\pi(R_0^2 - R_i^2)$, *minimum length of bytes* is $\frac{\lambda/2 \cdot NA}{2} \div mxk$ and *amount of required data* is *user data* x *redundancy data* x *spare region*, and where R_o and R_i are the outer and inner radii, respectively, of a recordable region on the optical disc, m is the number of channel bits per minimum mark, and k is the number of channel bits per byte.

[0033] For the 4.7-gigabyte DVD-RAM standard which has a sector configuration of 2,697 bytes per sector, a recording diameter of 24,100 to 57,500 μm and a spare region of 3%, assuming that for the mathematical relation [4] the wavelength of a laser beam is 400 nm and the numerical aperture is 0.6, the track pitch can be widened up to 0.473 μm for storage of 15-gigabyte of data. Also, if the wavelength of a laser beam is 400 nm and the NA is 0.65, the track pitch can be increased up to 0.427 μm for 18-gigabyte data storage.

[0034] Figures 6 and 7 show waveforms illustrating the jitter characteristics by shallow grooves and deep grooves at a slant angle of 80°, respectively, which are measured by oscilloscopy.

[0035] Table 2 shows that the jitter characteristics are similar between shallow grooves and deep grooves slanted at the same angle as the grooves.

Table 2

	Shallow grooves		Deep grooves
	$\lambda/6n$, 60°	$\lambda/6n$, 80°	$\lambda/3n$, 80°
Jitter (after equalization)	12.92%	11.97%	11.69%

[0036] The substrate with deep grooves according to the present invention can be compatible with a 4.7-gigabyte DVD-RAM by merely changing the position of a header pit to avoid phase reversal of a push-pull signal by deep grooves.

[0037] In the substrate according to the present invention, the depth and the slant angle of grooves are delimited using the mathematical relations [1] through [4], so that the maximum track pitch can be increased up to approximately 0.42 μm or more for 15-gigabyte or 18-gigabyte optical disc with improved crosstalk, cross erase and tracking characteristics.

[0038] While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention as defined by the appended claims.

[0039] The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

[0040] All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0041] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings), may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0042] The invention is not restricted to the details of the foregoing embodiment(s). The invention extend to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. An optical disc substrate for land-and-groove recording, comprising:

   a plurality of deep grooves (3) having a predetermined depth, individual deep grooves having sidewalls slanted at an angle of θ; and

   a plurality of lands (5) having the same level as the surface of the substrate (1),
   wherein a depth D of a groove for minimum crosstalk is determined by the following mathematical relation [1]

$$D = 0.4022\text{-}0.4574x\ A\text{+}0.6458x\ A^2 \qquad [1]$$

   Where $D = physical\ groove\ depth\ x\frac{n}{\lambda}$

$$A = \frac{NA \cdot TP}{\lambda} x \frac{1}{\sin^2\theta}$$

   TR indicates the track pitch of a disc substrate,

   NA indicates the numerical aperture of an objective lens of an optical pickup,

   θ is the slant angle of grooves between lateral extension of lands or grooves and extension of groove sidewalls,

λ is the wavelength of a laser beam of the optical pickup; and

n is the refractive index of the substrate.

2. The optical disc substrate of claim 1, wherein an effective groove depth D_{eff} is determined by the following mathematical relation [2]

$$D_{eff} = D \pm 0.844 \cdot NA \qquad [2]$$

3. The optical disc substrate of claim 1 or 2, wherein the track pitch TR and slant angle θ of grooves satisfies the following relations [3] and [4]

$$\tan\theta \geq \frac{D}{TP - W_m} \qquad [3]$$

where W_m is the width of a minimum record mark, and

$$\sin^2\theta \geq 1.25x\frac{NA \cdot TP}{\lambda} \qquad [4].$$

FIG.1

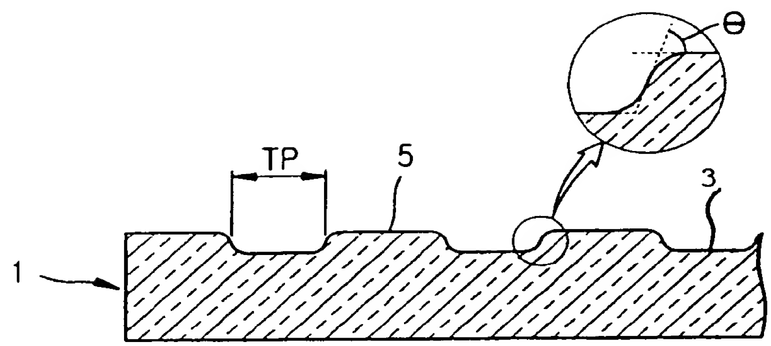
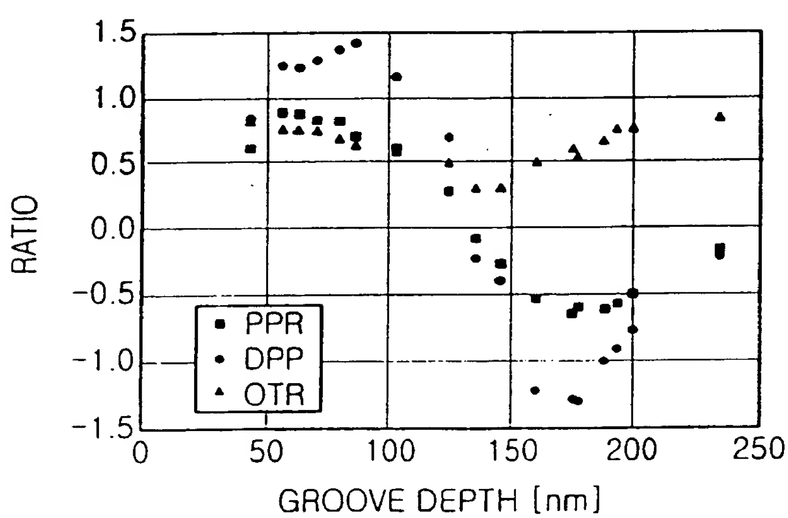

θ
TP
5
3
1

FIG.2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1.0
0.5
0.0
-0.5
-1.0
-1.5
RATIO
PPR
DPP
OTR
0
50
100
150
200
250
GROOVE DEPTH [nm]

FIG.3

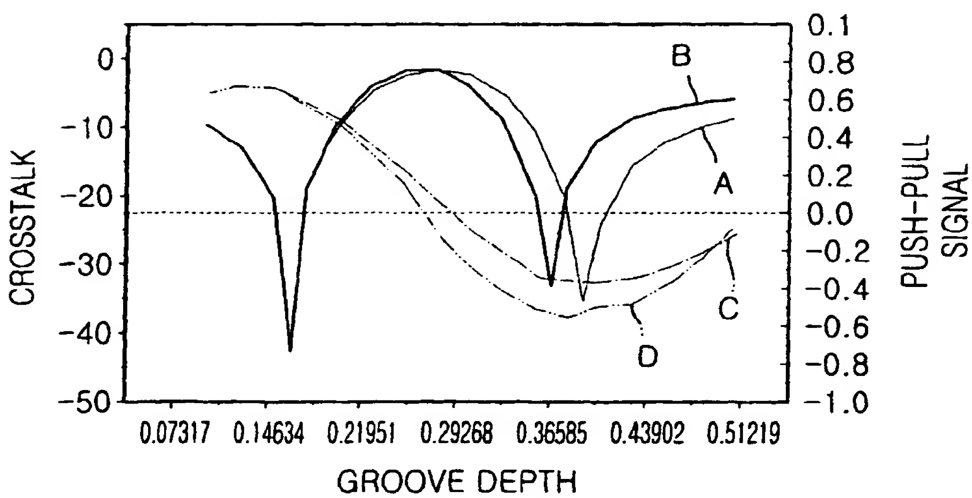

CROSSTALK
0
-10
-20
-30
-40
-50
0.1
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
PUSH-PULL SIGNAL
A
B
C
D
0.07317
0.14634
0.21951
0.29268
0.36585
0.43902
0.51219
GROOVE DEPTH

FIG.4

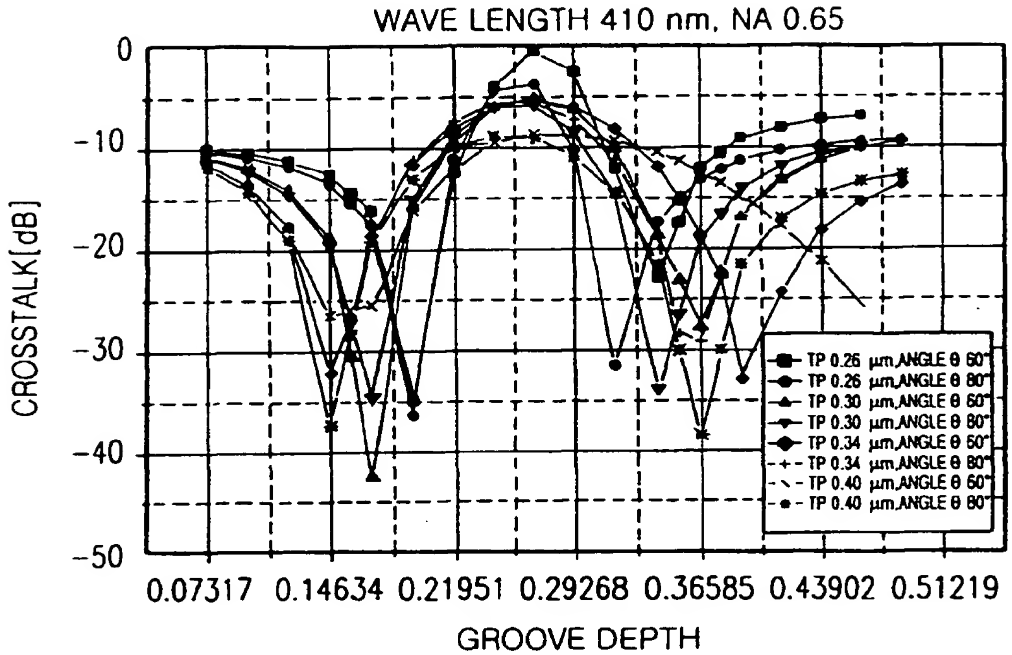

WAVE LENGTH 410 nm, NA 0.65
CROSSTALK[dB]
0
-10
-20
-30
-40
-50
0.07317
0.14634
0.21951
0.29268
0.36585
0.43902
0.51219
GROOVE DEPTH
TP 0.26 μm,ANGLE θ 60°
TP 0.26 μm,ANGLE θ 80°
TP 0.30 μm,ANGLE θ 60°
TP 0.30 μm,ANGLE θ 80°
TP 0.34 μm,ANGLE θ 60°
TP 0.34 μm,ANGLE θ 80°
TP 0.40 μm,ANGLE θ 60°
TP 0.40 μm,ANGLE θ 80°

FIG.5

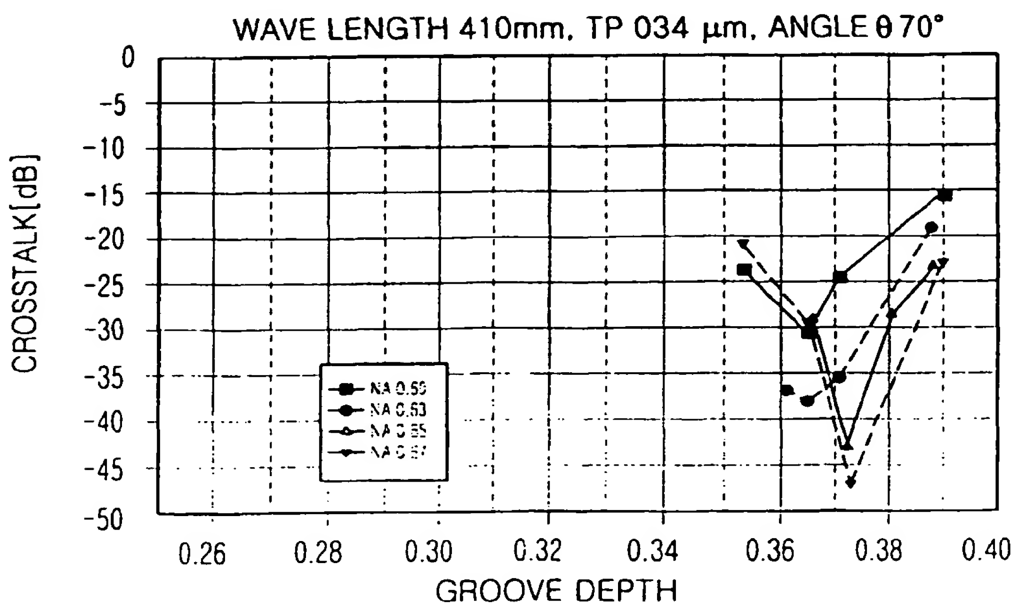
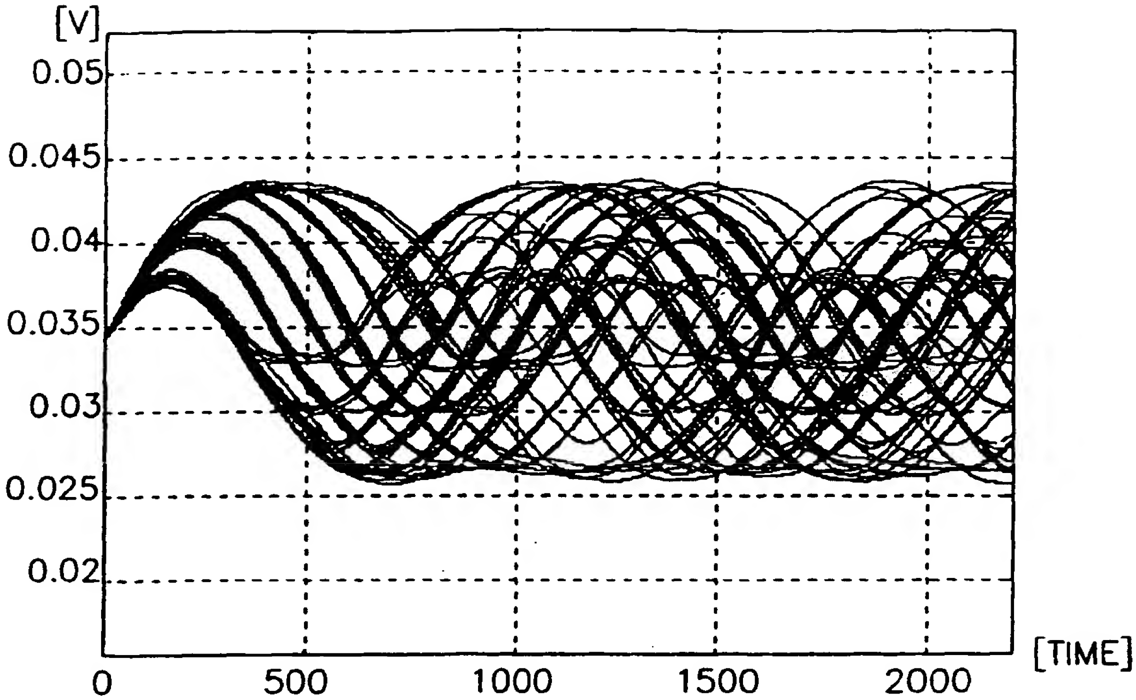

WAVE LENGTH 410mm, TP 034 μm, ANGLE θ 70°
CROSSTALK[dB]
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0.26
0.28
0.30
0.32
0.34
0.36
0.38
0.40
GROOVE DEPTH
NA 0.63

FIG.6


[V]
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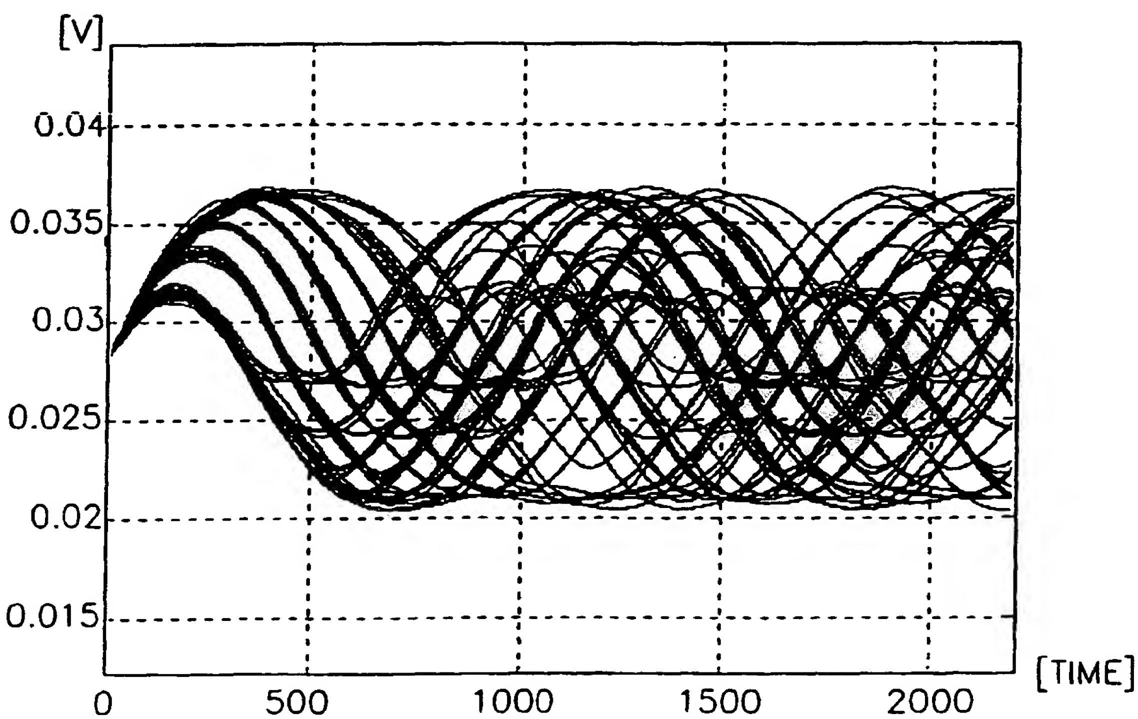
0.045
0.04
0.035
0.03
0.025
0.02
0
500
1000
1500
2000
[TIME]

FIG.7


[V]
0.04
0.035
0.03
0.025
0.02
0.015
0
500
1000
1500
2000
[TIME]

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(54) **Optical disc substrate**

(57) An optical disc substrate (1) with deep grooves (3) having a depth of $\lambda/4n$ to $\lambda/2n$, where λ is the wavelength of a laser beam of an optical pickup and n is the refractive index of a substrate. The optical disc substrate includes: a plurality of deep grooves (3) having a predetermined depth, individual deep grooves having sidewalls slanted at an angle of θ; and a plurality of lands (5) having the same level as the surface of the substrate, wherein a depth D of a groove for minimum crosstalk is determined by the following mathematical relation

$$D = 0.4022 - 0.4574 \times A + 0.6458 \times A^2$$

Where D = *physical groove depth* $\times \frac{n}{\lambda}$

$$A = \frac{NA \cdot TP}{\lambda} \times \frac{1}{\sin^2\theta},$$

TR indicates the track pitch of a disc substrate,
NA indicates the numerical aperture of an objective lens of an optical pickup,
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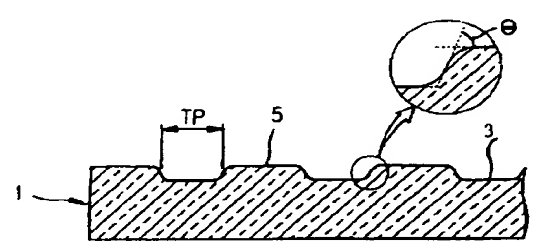
λ is the wavelength of a laser beam of the optical pickup; and
n is the refractive index of the substrate.

FIG.1



EP 1 039 451 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 30 2369

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 0 880 130 A (NIPPON KOGAKU KK) 25 November 1998 (1998-11-25) * the whole document * ---	1	G11B7/007 G11B11/105
X	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 08, 30 June 1999 (1999-06-30) -& JP 11 066627 A (TOSHIBA CORP), 9 March 1999 (1999-03-09) * abstract * -& US 6 154 440 A 28 November 2000 (2000-11-28) cited for language reasons ---	1	
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